

# Calibration of SLR System Delays for the European Laser Timing Reaching 20 ps Accuracy

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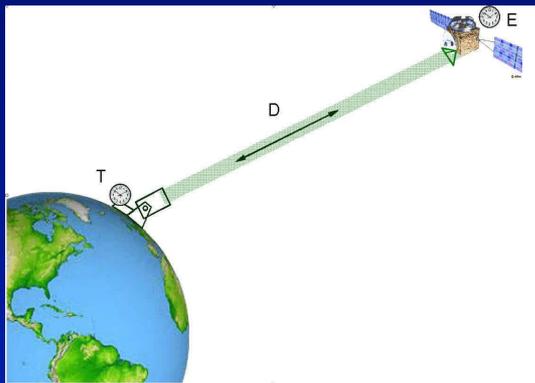
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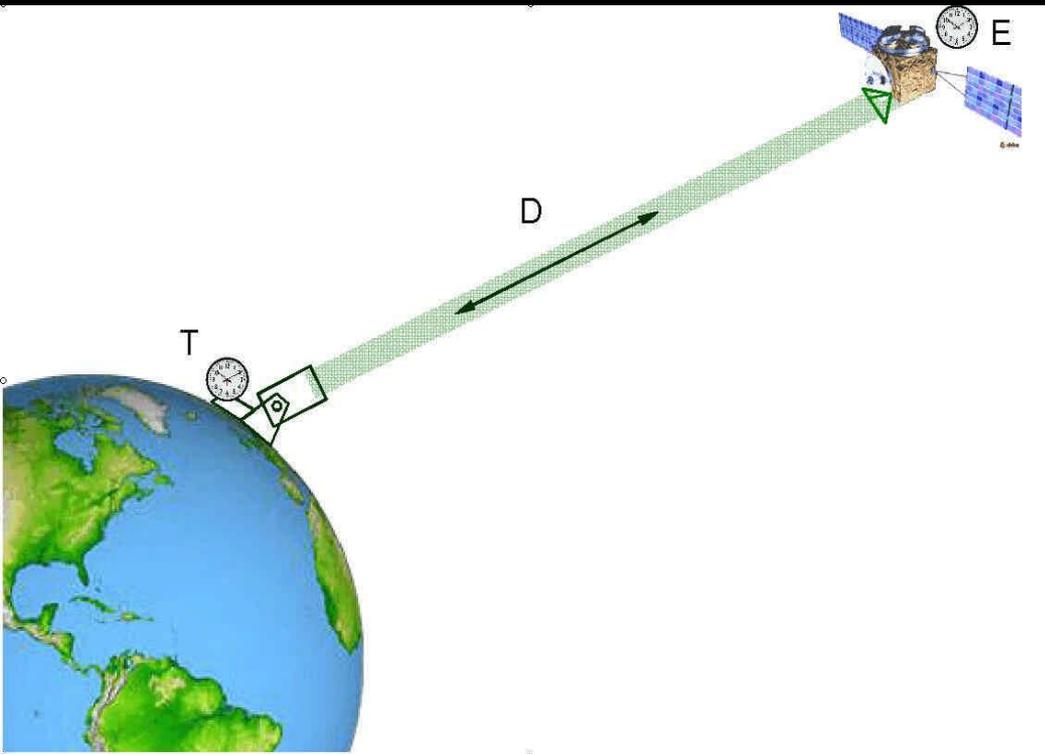
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# GOALS

- Development and tests of calibration procedures, which would guarantee ground - ground laser time transfer accuracy better than 25 ps
- Testing of these procedures in both laboratory and real field conditions
- Test of the breadboard of the ELT Calibration Device



# Principle - Laser Time Transfer in Space



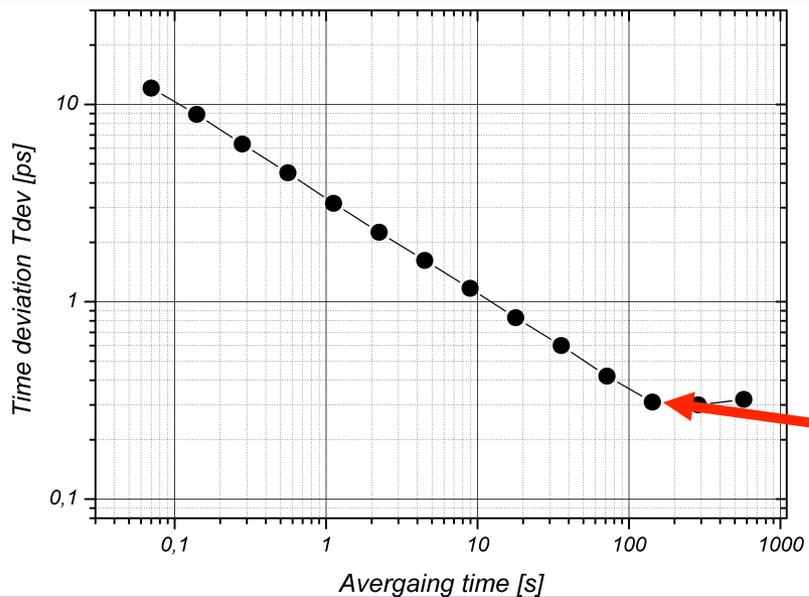
- Time and frequency transfer using ps laser pulses in space

- Relying on available technology and ground segment  
Satellite Laser Ranging

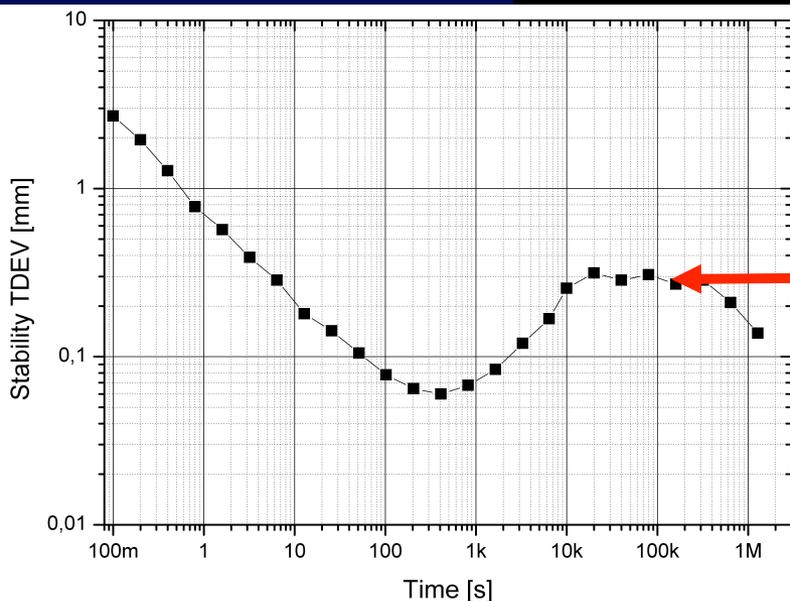
- Superb precision and accuracy:  
Tropospheric delays mapped by two way SLR on ps level

- Operational missions
  - T2L2 – joint CNES & NASA mission JASON-2
  - LTT – Compass / Beidou GNSS network
- Provide ~ 100 ps accuracy

# Existing SLR technology performance

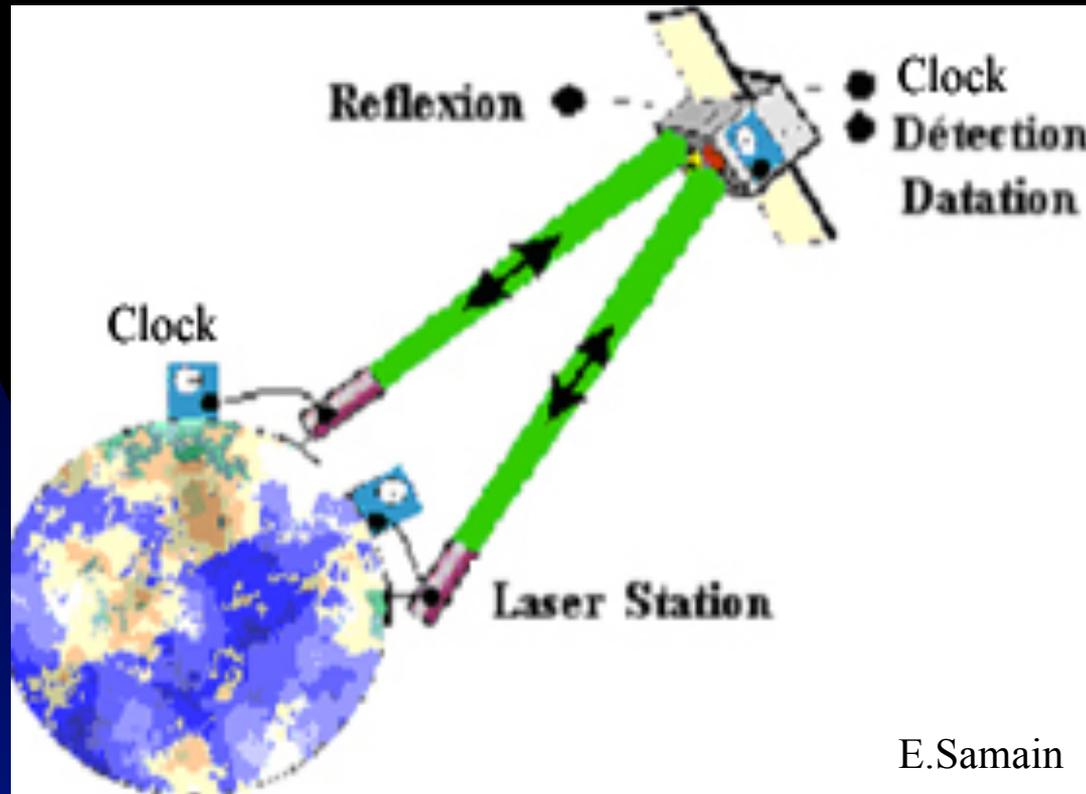


- SLR station Graz, G. Kirchner et al,
- One way propagation time  
GNSS laser ranging, one way
- Precision limit TDEV ~ 0.3 ps @ 100 s



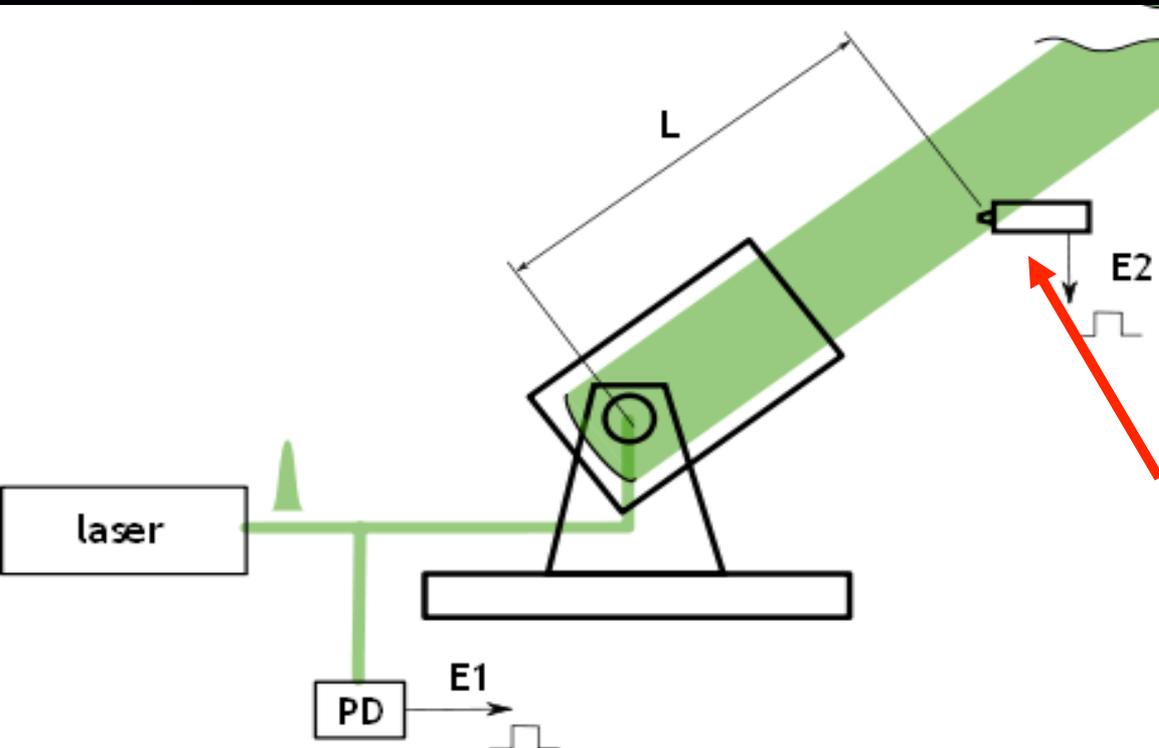
- System long term stability
- Stability TDEV ~ 2 ps @ 1s.... weeks

# Problem in - Laser Time Transfer Ground - Ground



- Systematic delays related to each SLR ground system
- Station time “1pps” versus epoch of crossing of laser pulse the system reference point

# ACES ELT Ground Station Calibration



The ground station will be characterized by a single calibration value / station

Calibration value computed from -  
epoch dif.  $(E2-E1)$   
- geometry distance  $L$

Calibration Device consisting of :  
- ELT type detector package  
- Epoch Timing system ET

Will be kept stable (delay) within  
entire ELT mission

Epoch E1 recorded using standard SLR system

Epoch E2 recorded using ELT Calibration Device (Detector & Timing device)

Both systems use common time (1 pps) & frequency

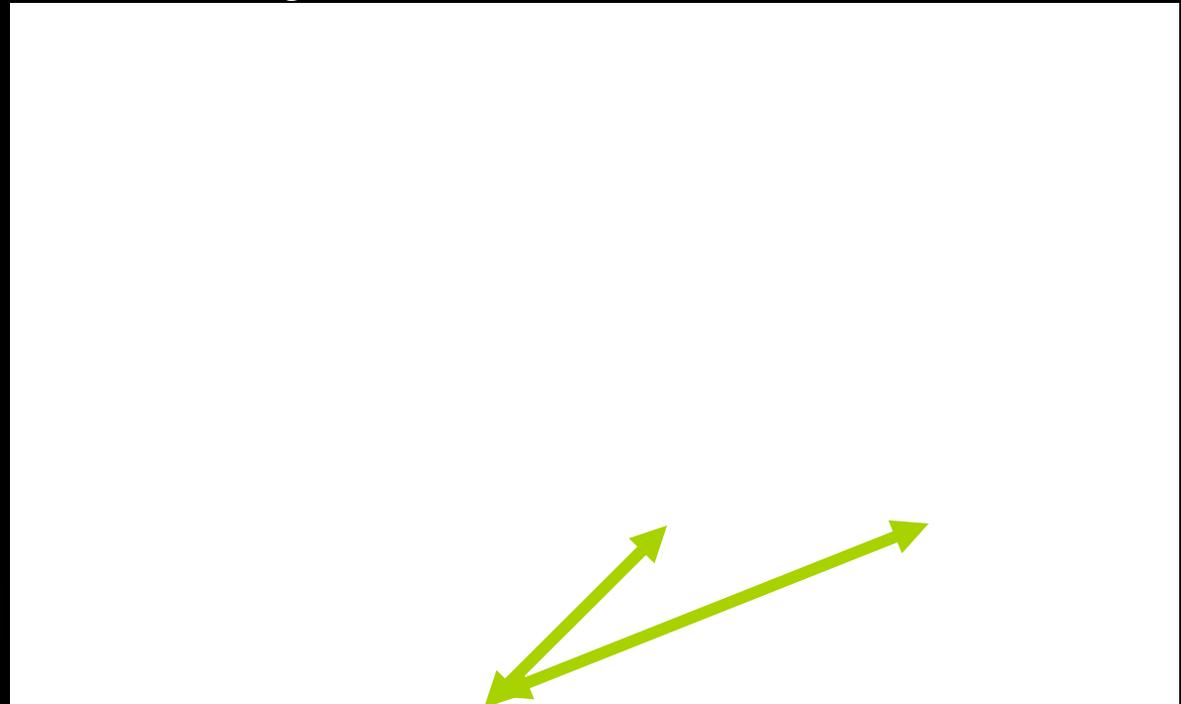
# ELT Calibration Device test # 1, WLRs

Fundamental Station Wettzell, Germany, February – May , 2014

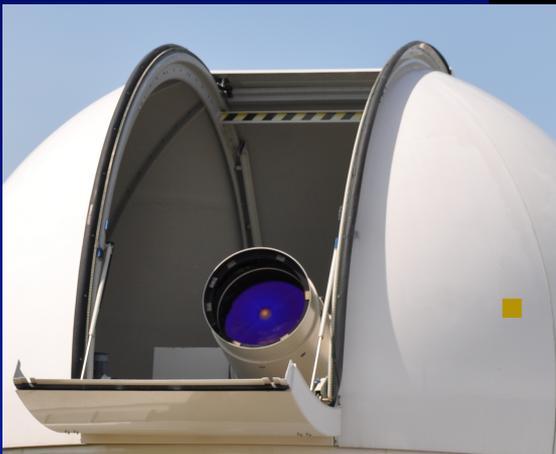


- ELT type detector package in front of SLR telescope distance surveyed repeatedly ( $< \pm 1\text{mm}$ )

- Event timing NPET



- Epoch reference “1pps” connected consecutively to SLR and ELT timing systems using identical cable



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# ELT Calibration Device Performance

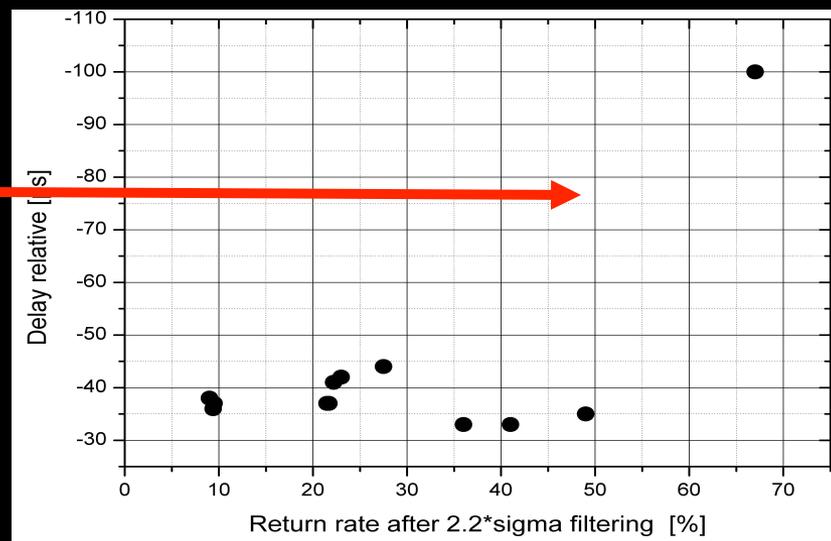
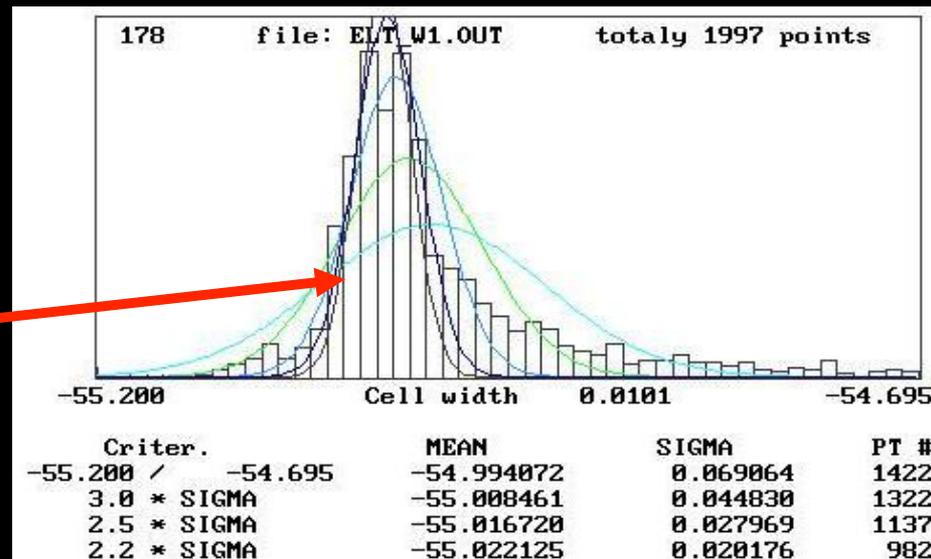
Fundamental Station

Wetzell, Germany, February 13-14, 2014

- Timing resolution test  
20 Hz, 10 ps laser FWHM, 8% rate

- Jitter ~ 20 ps rms

- Dynamical range 0.. 50 % (!!!)  
within +/- 6 ps half p-p  
(good for SLR tracking..)



# ELT Calibration Device Performance

Fundamental

Station Wettzell, Germany, February 13-14, 2014

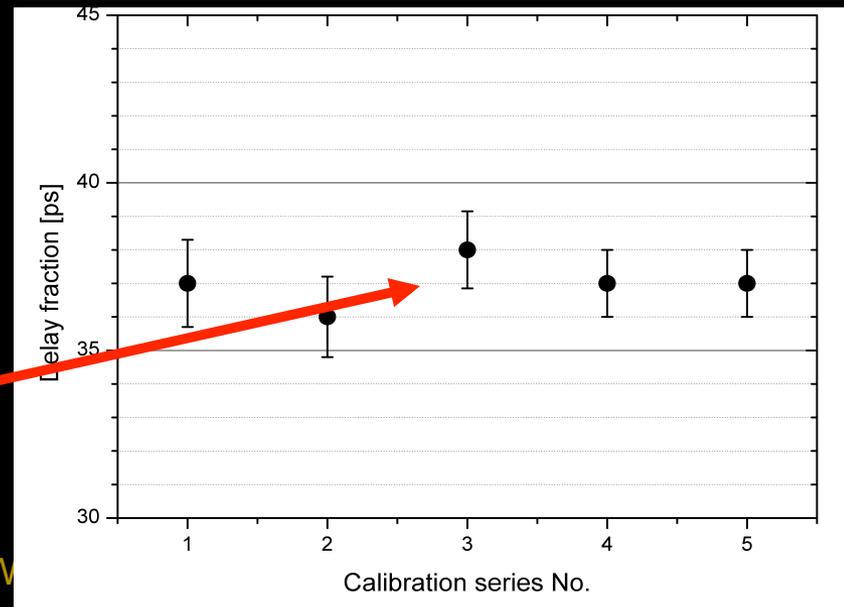
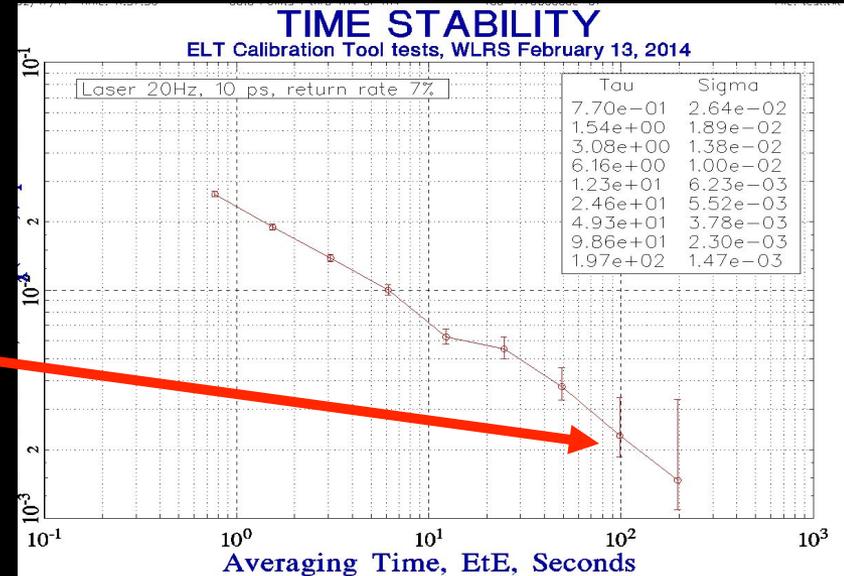
- 20 Hz, 10 ps laser FWHM, 8% rate

- TDEV 2.3 ps @ 100 s averaging

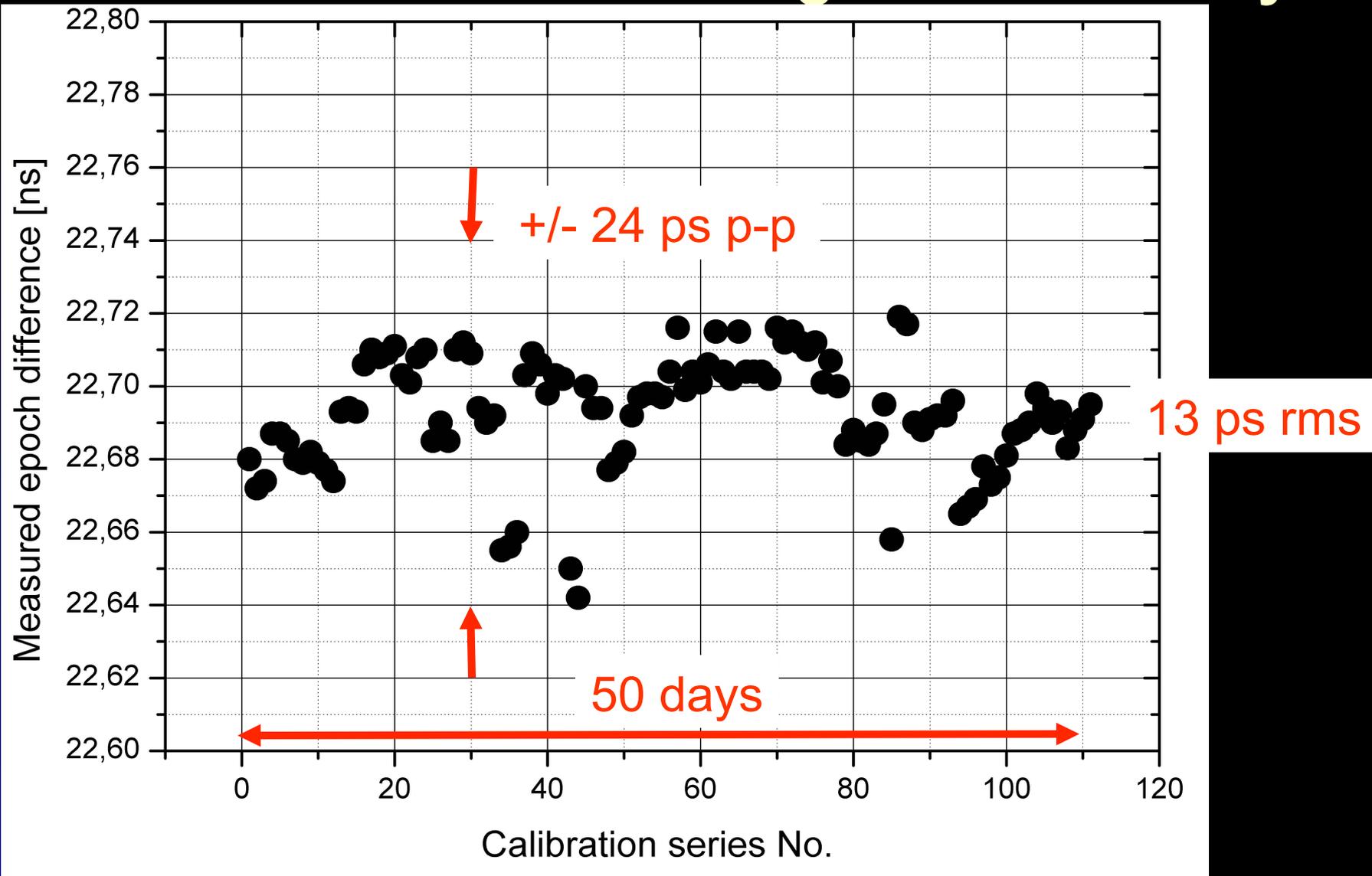
- 100 s series simulating ISS / ACES path in all other measurement

- Resulting in ~ 160 raw readings / path  
=> ~ 140 valid data points

- Series to series Stability +/- 1 ps



# ELT Calibration Long Term Stability



# ELT Calibration Device test # 1, WLRS

## RESULTS SUMMARY

The geometrical distance (see calib. session)  
=> one way propagation delay (air)

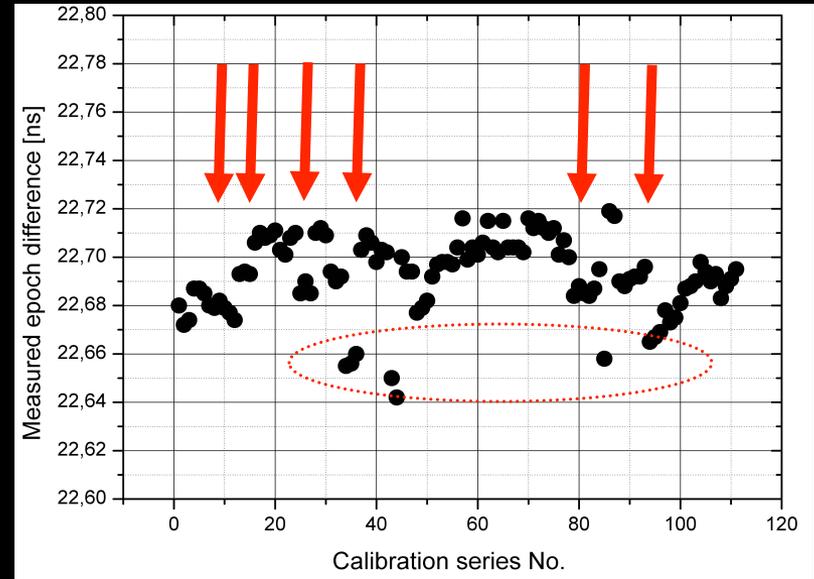
$D = 2302 \pm 1 \text{ mm}$   
 $DT = 7673 \pm 3 \text{ ps}$

Statistical spread between groups 1 - 2 ps without re-sync. effects

group to group jumps up to  
 $\pm 20 \text{ ps}$  p-p due to "1pps" cable  
delay variations / mechanical

Overall mean epochs difference  
 $22\,952 \pm 13 \text{ ps}$  (worst case est.)

$\pm 6 \text{ ps}$  omitting outliers



ELT calibration value WLRS

**ET = 15 279 ps  $\pm$  13 ps**

# CONCLUSION

- Calibration procedures, which do guarantee ground - ground laser time transfer accuracy better than 25 ps have been developed
- These procedures have been tested in both laboratory and real field conditions at Fundamental Station Wettzell, Germany
- Tests of the breadboard of the ELT Calibration Device were completed
- The Wettzell SLR system ELT calibration constant has been determined with a stability of +/- 13 ps over 2 months
- The ELT Calibration Device is expected to be completed by fall 2014 the calibration missions to European SLR stations are expected 2015-16



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